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MULTI-PASS AEROBRAKING PROJECT SUMMARY CASE 237

BELLCOMM
WASHINGTON, DC

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Bellcomm

955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

date: October 21, 1971

to: Distribution

from: R. N. Kostoff

subject: Multi-Pass Aerobraking Project Summary
Case 237

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ABSTRACT

A computer-oriented study of multi-pass aerobraking missions of a vehicle going from synchronous earth orbit to low earth orbit has been completed. Results generally corroborate those reported in previous studies.(1,2,3,4) This document contains a summary of the important results, as well as recommendations for future studies in the area.

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MEMORANDUM FOR FILE

VEHICLE DESIGN AND OPERATIONAL CONSIDERATIONS

The effects of varying different parameters pertinent to aerobraking reentry from synchronous orbit will now be described.

1. Configuration

Three heat shield configurations were examined: a hemisphere (drag coefficient $\sim$ 1.0), a cylinder with axis aligned normal to flow (drag coefficient $\sim$ 1.25), and a flat plate aligned normal to flow (drag coefficient $\sim$ 1.70). For fixed frontal area and vehicle mass, stagnation region heating rate is highest for the hemisphere, and lowest for the flat plate. For varying frontal area and fixed vehicle mass, stagnation heating rate decreases as the hemisphere and cylinder radii increase, and as the flat plate dimensions increase. Again, for fixed frontal area and fixed mass, the hemisphere decelerates at the lowest altitudes due to its low drag coefficient (high ballistic coefficient), and experiences the highest heating and force loads; the flat plate decelerates at the highest altitudes due to its high drag coefficient (low ballistic coefficient), and experiences the lowest heating and force loads.

2. Lift/Drag Coefficient

Three values of L/D were used, 0.3, 0.0, -0.3. Use of negative lift increases vehicle guidance accuracy requirements, but decreases heating and force loads. Also, employment of negative lift makes the mission more sensitive to deviations of the atmosphere density from a predicted nominal. On the other hand, use of positive lift increases heating and pressure loads, reduces vehicle guidance accuracy requirements substantially, and makes the mission less sensitive to atmosphere uncertainties. For a mission with a fixed number of passes, use of positive lift requires a larger entry angle than for negative lift.

3. Ballistic Coefficient

Three values of ballistic coefficient were used, 4 lbs/ft^2, 20, and 100. As ballistic coefficient increases, the vehicle decelerates at lower altitudes. Due to the increased air density at the lower altitudes, heating and force loads increase. To obtain large decreases in ballistic coefficient, it is necessary to substantially increase the vehicle frontal area. For the tug, it may be possible to obtain the required area increase by incorporating the existing meteoroid bumper into the thermal protection system.

4. Number of Passes

One pass to five pass missions were examined. As the number of passes in the mission increases, heating and force loads decrease. The rate of decrease is largest as the number of passes goes from one to two, and decreases continually thereafter. Trajectory corrections may be applied between passes at ellipse apoapsis with minute fuel expenditures. Mission flight time may be approximated by multiplying the number of passes in the mission by four hours. Thus, a five pass mission takes about twenty hours.

During a multi-pass mission, maximum stagnation region heating of the mission occurs during the first pass near periapsis, and the maximum which occurs on each succeeding pass monotonically decreases. This statement is valid for the three values of L/D used. Maximum stagnation region dynamic pressure exhibits somewhat different behavior. During the multi-pass mission, dynamic pressure decreases after the first pass to a minimum value at one of the intermediate passes, then increases continually until the last pass. For $L/D = -0.3$, the maximum dynamic pressure on the last pass is substantially higher than that on the first pass, and is the mission maximum. In the case of ballistic entry, $L/D = 0.0$, maximum dynamic pressure on the last pass is slightly higher than that of the first pass, but is still the mission maximum. When positive lift ($L/D = 0.3$) is employed, maximum dynamic pressure on the first pass is now slightly higher than that of the last pass, and it becomes the mission maximum.

5. Heat Shield Materials

Three types of heat shield materials, coated Columbium (maximum recycling operating temperature $\sim$ 2900°R, early shuttle era readiness), coated Tantalum ($\sim$4000°R, shuttle era), and Carbon-Carbon or ZrB_2 alloy ($\sim$4500°R, late shuttle era), were briefly examined. Use of Carbon-Carbon allows single pass aerobraking missions for all conditions studied. Employment of coated Tantalum allows single pass missions for the low ballistic coefficient vehicles, but requires at least a two pass mission for the high ballistic coefficient vehicles. Finally, utilization of coated Columbium allows a single pass mission for the lowest ballistic coefficient vehicle, requires a two pass mission for the intermediate ballistic coefficient vehicle, and necessitates a fifteen pass mission for the highest ballistic coefficient vehicle examined.

RECOMMENDATIONS FOR FUTURE WORK

A study which could be performed by three or four specialists in about a year is outlined.

Four major areas should be pursued, namely analyses of trajectories, configurations, navigation, and atmospheric effects. They are, of course, interrelated, and the successful performance of the study would require continuous interaction among the specialists.

The Trajectory Analyst would:

1) Specify L/D requirements to obtain desired trajectories.

2) Specify optimal trajectory locations for applying corrections.

3) Show trajectory perturbations due to:

   a. Atmosphere uncertainties.

   b. Attitude control (L/D) errors.

   c. Tracking errors.

Most of the above results would require extensive computer usage, although some perturbation results could be obtained analytically.

The Configuration Specialist would:

1) Perform aerodynamic studies on novel lifting vehicles.

2) Specify experimental aerodynamic data required.

3) Examine different thermal protection concepts.

4) Specify materials required for TPS.

5) Specify materials now available for TPS.

The Navigation Expert would:

1) Specify tracking accuracies desired.

2) Specify tracking accuracies now obtainable.

3) Specify on-board/earth-based sensors required.

4) Specify attitude control accuracy possible.

5) Specify attitude control system.

6) Relate attitude control propellant weight to accuracy.

Finally, the Atmospheric Specialist would:

1) Specify expected atmosphere uncertainty.

2) Specify communication blackout region.

3) Specify atmosphere composition along the trajectory.

In addition, possible guidelines could include short time return mission, on-orbit tug assembly if necessary, realistic prototypes for manned tugs, and single pass entry survival capability for safety.

For a study of this magnitude, it would be advisable to select a contractor with an already developed aerobraking computer program. Otherwise, valuable time would have to be expended in developing such a program.

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